Improving the visualisation of polarimetric response in SAR imagery - from pixels to images

Iain H. Woodhouse[1], Dean Turner[1], David H. Laidlaw[2]
[1]The University of Edinburgh, Dept. of Geography, Edinburgh, EH8 9XP, Scotland, I.H.Woodhouse@ed.ac.uk
[2]Computer Science Department, Brown University, Providence, Rhode Island 02912, USA

Abstract— This paper presents a new method for the visualisation of polarimetric response patterns on a synoptic basis. The aim of this approach is to synthesise traditional polarimetric response graphs with the spatial overview provided by standard remote sensing image processing techniques. By doing this, an effective means of exploring phenomenological polarimetric response patterns is achieved, which may prove to be a valuable input for the development of modelling strategies and the application of polarimetry.

I. Introduction

The use of polarimetric SAR data for earth science applications is hindered by an incomplete understanding of the interactions of radar waves with multi-layered landscape elements such as forest and crop structures. Such understanding may be improved by exploring the data through visual interpretation. Current visualisation strategies for polarimetric radar data can be split into two broad categories. Firstly there are those which examine the full co- and cross-polarised response of individual covariance matrices, or averages of these matrices [1,2]. Secondly, there are techniques which attempt to apply standardised image processing techniques to polarimetric data sets in the form of grey scale intensity images [3, 4] , RGB composites [5, 6] or IHS (Intensity, Hue, Saturation) composites [7]. Both these approaches, however, provide only a partial representation of the data which may lead to erroneous or partial understandings of the nature of polarimetric response.

The exploration of polarimetric response patterns may be improved by visualising iconic representations of response graphs over large areas. This paper investigates a new technique which combines polarimetric response graphs with the synoptic overview which is characteristic of traditional pixel-based remotely sensed imagery.

II. Radar Polarimetry: Theory and Applications

Polarimetric radar data is a unique source of remotely sensed data in that it allows some assessment of the geometric properties within a resolution elements. As such, it has many possible applications areas, including forestry, agriculture and sea-ice mapping [8] . Present limitations on the development of such applications include an incomplete understanding of the nature of polarimetric response, and the lack of widespread data coverage of the types afforded from orbiting satellite platforms.

Fully polarimetric radar systems transmit and receive both horizontal and vertical waves, as well as the phases between them. This permits the measurement of the Kennaugh matrix **K** which characterises the backscattering properties of the ground resolution element. The technique of polarisation synthesis can be used to simulate the backscatter response (P) for any arbitrary combination of transmit and receive polarisations. This is achieved by multiplication of **K** by the Stokes vectors [S] for the transmit and receive polarisations (subscripted t and r respectively), so that

$$P=S_r \mathbf{K} S_t^T,$$

where, $S=[1, \cos2\psi\cos2\chi, \sin2\psi\cos2\chi, \sin2\chi]$, with the superscript T denoting the transpose. In this definition, ψ is the orientation angle (from 0-180° from horizontal) and χ is the ellipticity angle which ranges from -45° (right hand circular) to +45° (left hand circular). Since the range of χ and ψ can be taken as polar co-ordinates within a Poincaré sphere [9] the synthesised polarisation response (P) is an intensity pattern across the sphere.

Visualisation of polarimetric response patterns is therefore not straightforward, as each single measurement (be it a single pixel or a spatial average) produces many values. Particular difficulties are faced when attempting to view the data in a synoptic manner using traditional methods.

III. Visualisation of Polarimetric Response Patterns

The polarimetric response graph is effectively a lat-lon projection of the Poincaré sphere, presented either as a 2D contour plot [8] or, more usually, as a 3D surface. Normally two graphs are produced: the co-pol response, where the transmit and receive polarisations are the same, and the cross-pol response, where the two states are orthogonal. However, this method is unsuitable for representing patterns over large areas, and as such has failed to be widely adopted by those investigating applications of polarimetric radar. In these cases, visual interpretation is based around imaging techniques developed for visual and infra-red data i.e. grey-scale intensity images and RGB colour composites. This presents problems when considering how best to represent the full polarimetric response. The approach of multiple grey-scale images, for instance, whereby each image represents a sequential increase in either orientation or ellipticity angle

[1] Presented at IGARSS 2002, Toronto, 2002. This work was partially supported by NSF (CCR-0086065).

[4, 10] forces the user to switch attention between images, building relationships based on visual memory [11]. This approach can be regarded as sub-optimal for remotely sensed images, where the amount of detail in a single image inhibits the establishment of such relationships.

The use of RGB composites has similar problems, in that only three values can be represented in a single image. Typically, this results in composites being made from the three basic polarimetric measurements (HH, HV and VV) [5,6] although composites can be made using the phase data (e.g. HH+VV, HH-VV and HV). Other approaches include Optimum Polarisation Contrast Enhancement (OPCE) to select transmit and receive polarisations which optimise the difference between features of interest in the image. However, this requires the definition of regions that can be characterised by a distinctive polarimetric response [8].

Other visualisation strategies attempt to define polarimetric response in terms of interaction type, such as surface, dihedral and volume scatterers. The degree to which a single resolution element is dominated by one type of scatterer can be derived from an entropy value, which is high for random targets, and low for coherent scatterers [12]. Imbo et al [7] have developed a technique which maps entropy and phase difference against a background span (total power) image. As phase difference is an angular parameter, they map it to hue. Entropy is subsequently inversely mapped to saturation, producing an image that is locally coloured only in areas where a dominant scattering mechanism exists, tending towards grey as the response becomes more random. This approach has the disadvantage that no extra information is given except for the most well-defined polarimetric response patterns. Thus its applicability to the study of forested areas, for instance, may be limited, as response patterns are unlikely to be dominated by any one single interaction type.

In summary, current visualisation techniques are unsatisfactory either due to the spatial constraints imposed by the polarisation response graph, or by the inevitable simplification required for any form of pixel-based imagery. An effective visualisation technique therefore requires a synthesis of these two different approaches.

IV. A SYNOPTIC APPROACH

One way to represent multivalued image data is to replace the pixel-based approach with an icon-based representation [13]. This affords visual analysis of the image from a number of scales – at the broad scale the entire image scene may appear as a standard image, but on closer inspection the multivalued nature of individual pixels can now be read individually, and with reference to neighbouring pixels across an area. We present here one possible iconic representation based on the polar azimuthal plot of the polarimetric response, described in detail in [14] . This has a number of advantages when compared to the traditional lat-lon plot, which can be seen from the schematic representation given as figure 1. Most notable is that the orientation angle is now mapped to an angle around the circumference of the globe, making the graph immediately more intuitive, as does the mapping of the left and right-handed polarisations to respective halves of the globe. Another advantage is the reduction of the 'data-ink ratio' [11] which is afforded by mapping the circular polarisations to the centre of the graph, where orientation angle is redundant [14] . Of course, in the current context, a circular representation is also more effectively used as a data icon.

This icon is used to produce a synoptic representation of polarimetric response patterns by first producing a 20x20 pixel image of the normalised polarimetric response globe for the co- and cross-polarised data for each pixel within the original image. Two span (total power) images are also produced – the first span image is resampled so that each pixel is enlarged to 20 square pixels, whereas the second is similar but with zero values for the areas occupied by the polarimetric response globes. Three of these four images can then be combined as an RGB composite – the optimum combination depends on the particular application at hand. Using the first span image produces an image which is

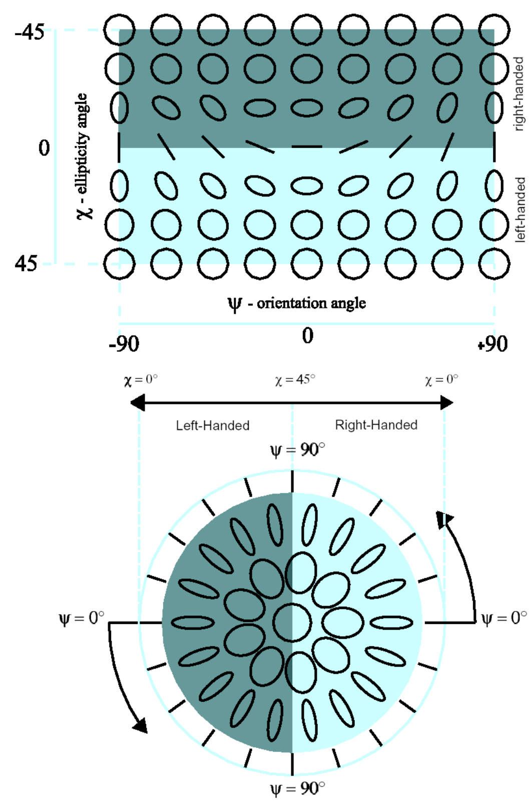

Figure 1. Schematic representation of Polarimetric Response Graphs: the upper graph is a 2D representation of the traditional graph, the lower shows the new polarisation response 'globe' [14].

dominated by the background intensity, and is useful in terms of overall image characteristics. The second image allows for a more detailed analysis of the polarimetric response patterns.

A further feature of the icon-based image, is that the icons are mapped using a hexagonal grid. This is visually less distracting than a square grid, and encourages relationships to be seen in the range direction, which should be more correlated than in azimuth. An example of the method is given in figure 2 and shows the response patterns over an area of reed beds in a C-band radar image of Siggefora Sweden [15]. In this case, there appears to be a very well defined pattern of response over a large region, which is replicated (to a lesser degree) in the L-band data. A more detailed interpretation of a similar data set is given in [16].

Areas which give well-defined, spatially correlated polarimetric response patterns tend to be those where a number of landscape factors are relatively invariant. For example, in figure 2, the reeds beds are regularly aligned. As they are found within a lake, it can be assumed that the slope and dielectric properties of the underlying surface are constant. This pattern is replicated in the L-band data, but occurs closer to the shore. This suggests that similar interactions are occurring with larger and more densely packed reeds in this area. Such patterns do not occur in areas where slope angle, soil moisture and canopy structure are highly variable. A possible improvement on this technique would be to separate the response patterns into those formed by coherent scattering mechanisms (i.e. unimpeded surface backscatter), and those formed by incoherent scattering mechanisms (i.e. forest canopies). This could be achieved using interferometric data and would allow each scattering mechanism to be visualised and examined separately.

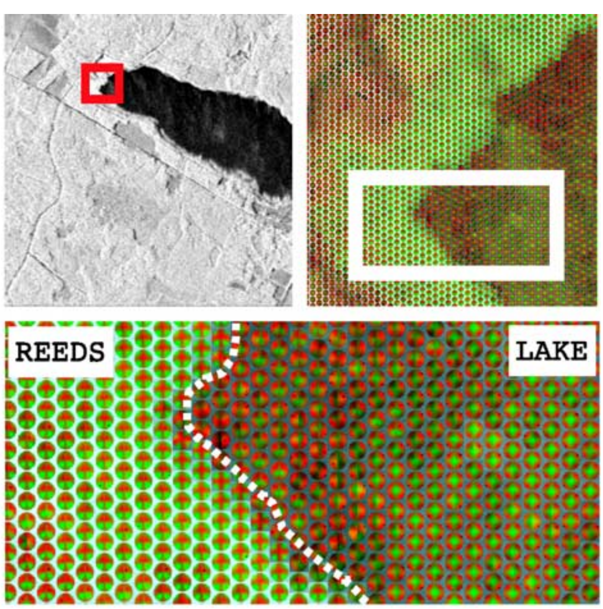

Figure 2. Example of polarimetric response globe visualisation: zoom detail shows a coherent change in response pattern between the lake surface and reed beds. Note that individual response patterns can be read as the scale increases.

V. CONCLUSION

The density of data produced from a single pixel measurement, and the relative infancy of the technology have contributed to the limited use of fully polarimetric data. Visualisation of polarimetric data has, to date, relied on either response graphs for single regions, or the application of standard image processing techniques. In the former case, the spatial nature of the data is ignored, whereas in the latter case, only a very small subset of the different polarisations can be viewed at one time. In response to this, a new technique has been developed which allows the synoptic representation of polarimetric response patterns. Initial results have been encouraging, although the best results have come from areas where the polarimetric response is well defined. Future research will concentrate on reducing the variability of response patterns by accounting for factors such as incidence angle, slope and backscatter coherence.

REFERENCES

[1] A.P. Agrawal and W.M. Boerner. Redevelopment of Kennaughs Target Characteristic Polarization State Theory Using the Polarization Transformation Ratio Formalism for the Coherent Case. *Trans. Geosci. Rem. Sens.*, 27(1):2-14, 1989.

[2] Y. Dong and B.Forster. Understanding of Partial Polarisation in Polarimetric SAR data. *Int. Jour. Rem. Sens.*, 17(12):2467-2475, 1996.

[3] H.Skriver et al. Multitemporal C- and L- Band Polarimetric Signatures of Crops. *Trans. Geosci. Rem. Sens.* , 37(5):2413-2429, 1999.

[4] J.J.Van Zyl et al. Imaging radar polarization signatures: Theory and Observation. *Radio Science*, 22(4):529-543, 1987.

[5] T.Le Toan et al. Relating Forest Biomass to SAR Data. *Trans. Geosci. Rem. Sens.*, 30(2):403-411, 1992.

[6] E.L. Christensen et al. EMISAR: An Absolutely Calibrated Polarimetric L- and C- band SAR. *Trans. Geosci. Rem. Sens.*, 36(6):1852-1865, 1998.

[7] P.Imbo et al. Synoptic representation of the polarimetric information. In R.A. Harris and L. Ouvrehand, editors, CEOS SAR Workshop, pp 341-346, Toulouse, France, 1999. ESA Special Publications.

[8] F.M. Henderson and A.J. Lewis, eds. Principles and Applications of Imaging Radar , chpt 5: Polarimetry in Radar Remote Sensing: Basic and Applied Concepts, pp. 271-356. New York: John Wiley & Sons, 1998.

[9] F.T. Ulaby and S. Elachi. Radar Polarimetry for Geoscience Applications. Artech House, Norwood, MA, 1990.

[10] H.A Zebker and J.J. Van Zyl. Imaging Radar Polarimetry : A Review . *Proceedings of the IEEE*, 79(11):1583-1606, 1991.

[11] E.R. Tufte. The Visual Display of Quantitative Information. Graphics Press, Cheshire, Connecticut, 1983.

[12] S.R. Cloude and E.~Pottier. An Entropy Based Classification Scheme for Land Applications of Polarimetric SAR. Trans. Geosci. Rem. Sens. , 35(1):68-78, 1997.

[13] D.H. Laidlaw et al. Applying Painting Concepts to the Visual Representation of Multi-Valued Scientific Data. Proceeding of SIGGRAPH 98, New Orleans, Louisiana, 1998.

[14] I.H. Woodhouse and D. Turner. On the Visualisation of Polarimetric Response. Submitted to *Int. Jour. Rem. Sens.*, September 2001.

[15] I.H. Woodhouse and D. Hoekman. Radar modelling of coniferous forest using a tree growth model. *Int. Jour. Rem. Sens.*, 21(8):1725-1737, 2000.

[16] D. Turner, I.H. Woodhouse and D.H. Laidlaw. A synoptic visualisation of fully polarimetric SAR data: an annotated example. *Proceedings of IGARSS, 24-28 June, 2002 Toronto*.